DEVELOPMENT OF THE DECAY CURVE OF PAVEMENT MARKING RETROREFLECTIVITY BASED ON A FIELD SURVEY

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ABSTRACT

Performances of retroreflectivity vary place to place, according to traffic volumes and time lengths after striping, depending on pavement marking materials and colors. The present paper uses the nation wide data of retroreflectivity, which has been collected from freeways and then tries to develop the regression curve setting traffic volume and service life as independent variables and retroreflectivities as dependent variables

The DB system includes two year's measurement in 2005~2006 over Korean freeway pavement marking at an interval of three months for the period. The mobile measurement system, a laserlux, was employed for the purpose. The DB has provided a lot of information about materials and performance of the specific pavement marking such as geometric features, traffic volumes, material characteristics and the installation date.

This study provides the comparison of pavement marking performances under diversified conditions. Based on accumulated pavement marking performances, this study provides performance curves based on the diversified factors. The goal of the retroreflectivity modeling is to develop equations that can be used to estimate an average retroreflectivity of pavement markings as a function time since application and traffic volume.

After representing the variation of retroreflectivities and estimating regression curves by linear, exponential, logarithmic and power function, the regression curve which had the highest coefficient of determination and the value similar to the last field measurement was regarded as the retroreflectivity decay model.

As a result of verification, the decay model showed the signification within the 90% confidence level and especially showed the clear relation with field data according to increase of cumulative vehicle exposure. Accordingly, these models can be used to determine service lives, retroreflectivity degradation rates, and retroreflectivity of new markings.

1. INTRODUCTION

Pavement marking retroreflectivity is known to be correlated to levels of traffic capacity or vehicle speeds. Performances of pavement marking retroreflectivity vary place to place, according to traffic volumes and time lengths after striping, depending on paint types and colors. Therefore, a lot of researches have been focused on factors correlated with levels of pavement marking retroreflectivity.

Literature Review

Studies by Scheuer (1997) have shown that winter maintenance activities, such as snowplowing, have a pronounced adverse effect on the retroreflectivity of pavement markings.

A study by Lee, J.T. *et al.* (1999) directly showed the relationship between pavement markings retroreflectivity and crashes were conducted by. The study, however, failed to establish a correlation between nighttime crashes and level of retroreflectivity.

Migletz, J. et al. (1999) provided results of field measurements of pavement marking retroreflectivity for sites under the jurisdiction of 32 states of USA. The economic implications of particular threshold values for replacement of pavement marking also suggested. For the above observations, there should be clear identification of the minimum pavement marking retroreflectivity. The minimum retroreflectivity exists as a minimum target to which observed pavement retroreflectivity values are satisfactory. The study of the minimum retroreflectivity is still on going worldwide.

Oh and Lee (2003) performed laboratory wearing test using accelerated loading simulator to identify the effect of traffic volume. Oh(2005) provides observation reports that under environmental field conditions, pavement marking retroreflectivity is relatively low at ramp of freeway other than at main lines of freeways and that pavement marking retroreflectivity is relatively low at climbing lanes and sharply curved sections.

Thamizharasan et al. (2003) identified three basic patterns in terms of the degradation or decay of retroreflectivity over time. The retroreflectivity for newly placed pavement markings increases initially because glass beads become exposed after some amount of wear, and then peaks before reducing over time as the pavement markings wear out. The retroreflectivity of older pavement markings is represented by a straight line and gradually decreases over time. He found that the line depicting the rate of degradation appeared to be linear for readings larger than 50 or 60 mcd/m^2/lux, a highly relevant finding given that if a minimum retroreflectivity value of 100 mcd/m2/lux is adopted, then a linear model to predict retroreflectivity degradation of older established markings may be sufficient.

2. RESEARCH APPROACH

Research Purposes

The performances of pavement marking retroreflectivity varies place to place, according to traffic volumes and time lengths after painting, depending on types and colors of pavement markings. Identification of the field pavement marking retroreflectivity place to place would provide the information over the retroreflectivity performance pattern under specific conditions. Additionally, it will provide the performance of pavement marking materials.

The purpose of this study is to develop retroreflectivity decay model using the nation wide cumulative data of freeway. Decay models establish a relationship between retroreflectivity and factors such as aging of markings and exposure to vehicle travel that contribute to the degradation of retroreflectivity. These models will be used to determine service lives, retroreflectivity degradation rates, and retroreflectivity of new markings.

Methodology for analysis

The present paper uses the nation wide data of retroreflectivity, which has been collected from freeways and then tries to develop the regression curve setting traffic volume and service life as independent variables and retroreflectivities as dependent variables.

- The decay model for pavement marking retroreflectivity by pavement marking colors is to be studied.
- The decay model for pavement marking retroreflectivity by time period exposure to traffics is to be studied
- The decay model for pavement marking retroreflectivity by traffic volume is to be studied.
- The decay model for pavement marking retroreflectivity pavement marking materials such as conventional type, durable, modified acrylic, waterborne type are to be studied.

Data Collection

The data collection of the pavement marking retroreflectivity had been performed over the Korea freeways. The target freeway lines include 6 freeway lines such as Kyonbu, Seohaean, Honam, Namhae, and Seoul ring freeway lines. The measurements were performed at an interval of three months for the period of two years from 2005 to 2006. The total number of measurements was six and

total length was up to 2,200km for each measurement. Figure 1 is a schematic map of target freeways.

The target pavement marking includes yellow centerlines and left-single-broken lines of the rightmost lane. The rightmost lane is the one that is often used by heavy vehicles and used most frequently by exit and entry vehicles. The pavement marking retroreflectivity data was obtained using Laserlux.

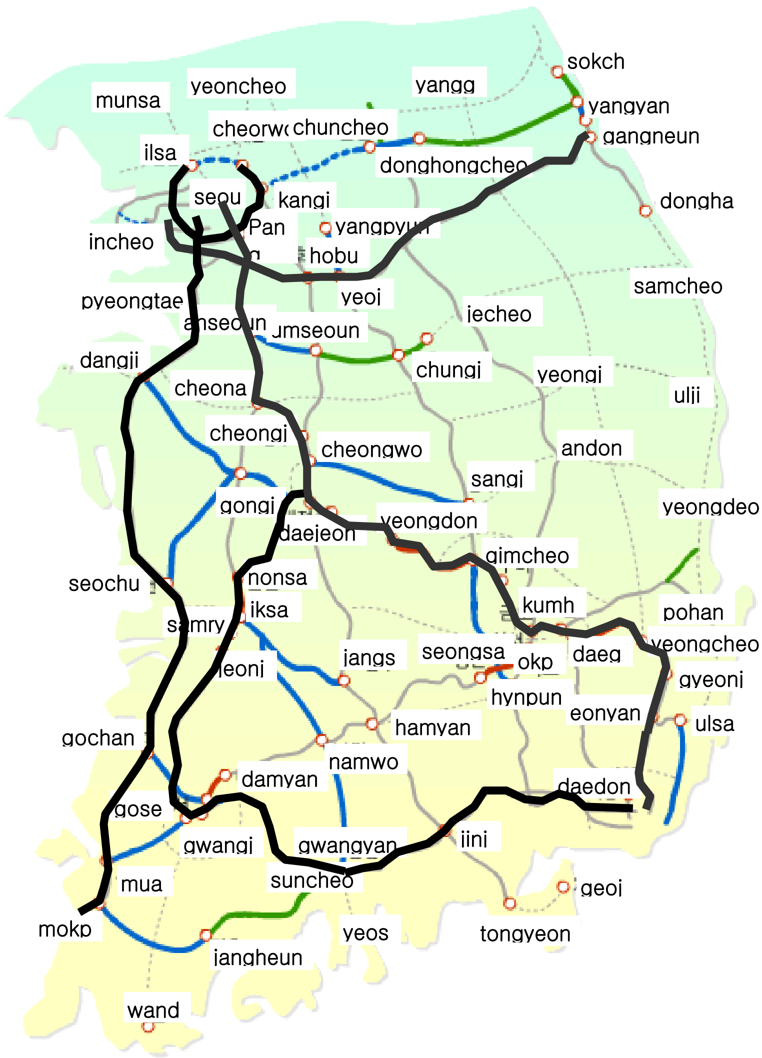


Figure 1. Skematic Map of Target Freeways

Database was constructed in two ways. First, retroreflectivity data for same type of marking from different survey locations were accumulated. Pavement marking were varied in material types and aging from installation across whole survey sections. So, it was possible to obtain dozens of retroreflectivity data for the specific material having various aging from installation and exposures to traffic. These data were used to develop a decay model that represents the average degradation of retroreflectivity of that pavement marking. Although pavement markings on various geographic regions have different climatic conditions, it is assumed that the climatic effect was slight in decay model in order to obtain data for a broad age period of markings.

Secondly, retroreflectivity data for the pavement marking on the specific site were accumulated. Since the total numbers of retroreflectivity readings at individual test sites was six for two years, it was sufficient to represent that the retroreflectivity variation of each marking during its entire life span. So, the retroreflectivity decay model of each site was represented by a separate model using six readings. These models were used to predict service life of a particular type of pavement marking and the residual life of the existing pavement marking.

Construction of Decay Model

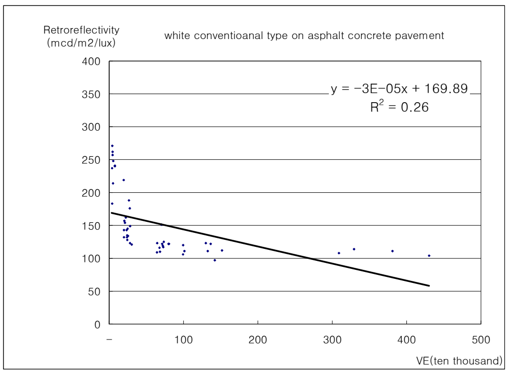
Regression analysis was conducted by setting retroreflectivities of pavement markings as dependent variables and aging and traffic volume as independent variables.
Aging and traffic volume were combined as a single variable since they had very high correlation each other.

CVE=Age・ ADT / Number of Lane / 100,000
Where, CVE : Cumulative Vehicle Exposure

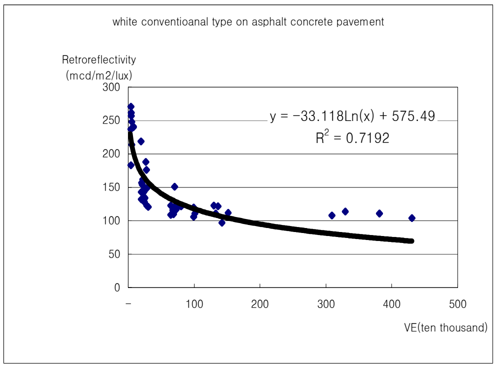
Regression analysis was conducted by using four models and the conformity was verified.
Linear model : $Y=a+bx$
Exponential model : $Y=a\cdot \exp(bx)$
Logarithmic model : $Y=a+b\cdot \ln(X)$
Power model : $Y=a\cdot X^b$
Where, Y : retroreflectivities of pavement markings
X : Cumulative Vehicle Exposure

After integrating total field data into a single database, CVE was calculated by investigating the installation day of markings and traffic volume on each site. The regression analysis for each pavement marking material was executed separately. After representing the variation of retroreflectivities and estimating regression curves by linear, exponential, logarithmic and power function, the regression curve which had the highest coefficient of determination and the value similar to the last field measurement was regarded as the retroreflectivity decay model.

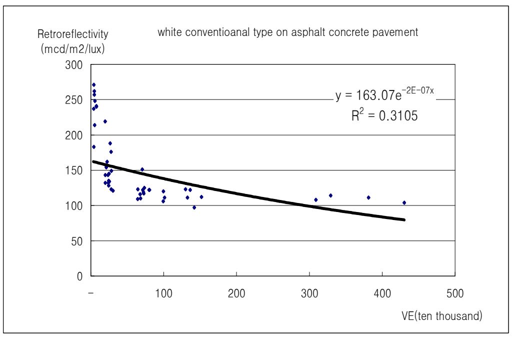
Figure 2 represents the regression curve for the white conventional type on asphalt concrete pavement. Coefficients of determination ranged from 0.26 to 0.76. After reviewing logarithmic model and power model that having high value of coefficient of determination, the power model which approached the last field measurement was adopted as the retroreflectivity decay model.



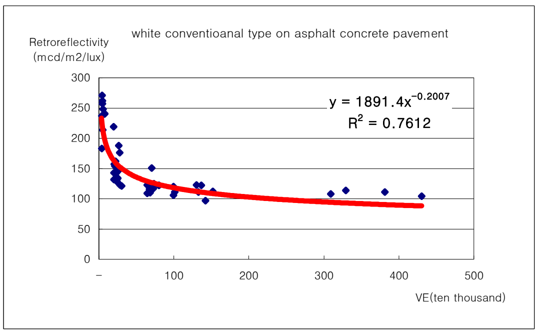
(a) Linear model



(b) Logarithmic model



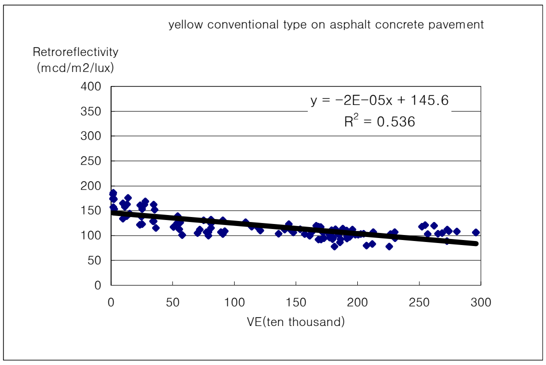
(c) Power model



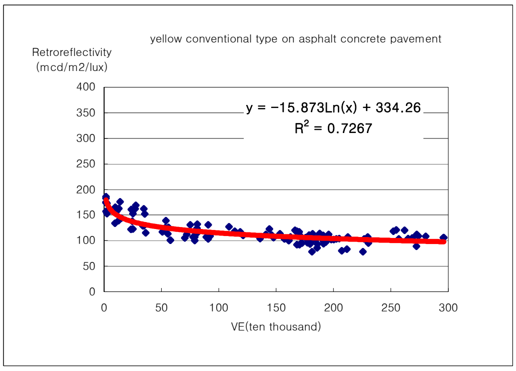
(d) Exponential model

Figure 2. Regression Curve for White Conventional Type on Asphalt

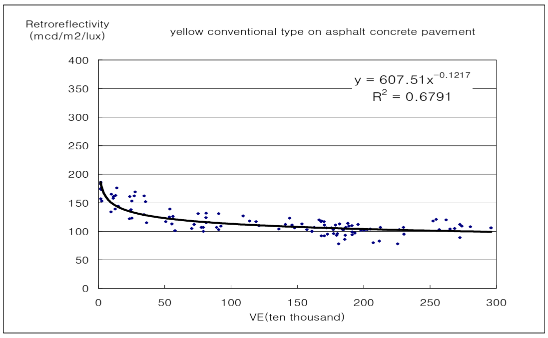
Figure 3 represents the regression curve for the yellow conventional type on asphalt concrete pavement. Coefficients of determination ranged from 0.53 to 0.72. After reviewing logarithmic model and power model that having high value of coefficient of determination, the logarithmic model which approached the last field measurement was adopted as the retroreflectivity decay model.



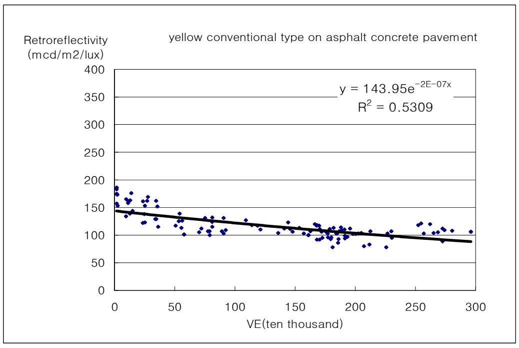
(a) Linear model



(b) Logarithmic model



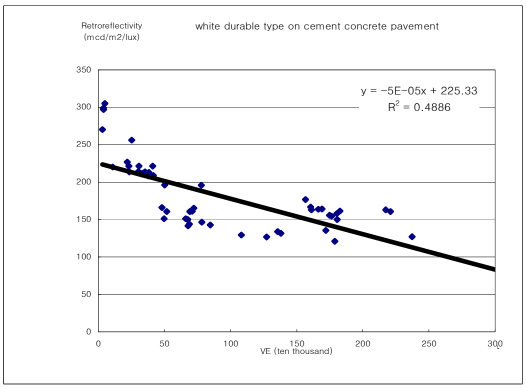
(c) Power model



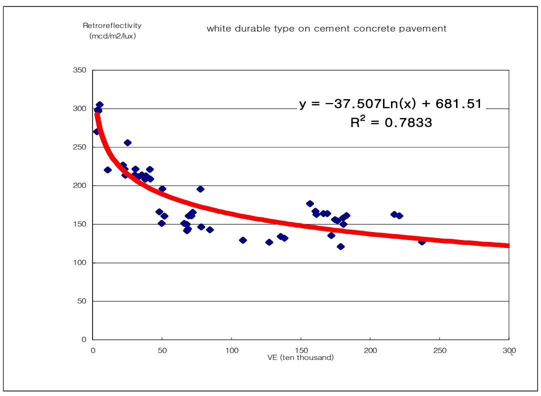
(d) Exponential model

Figure 3. Regression Curve for Yellow Conventional Type on Asphalt

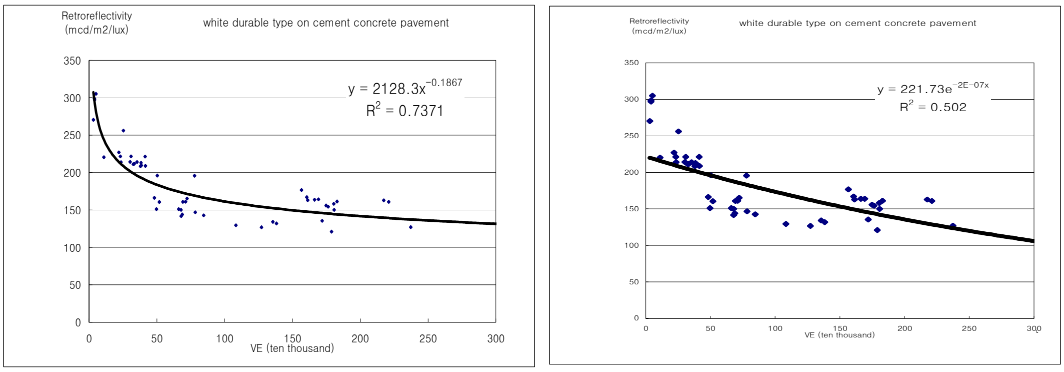
Figure 4 represents the regression curve for the white durable type on cement concrete pavement. Coefficients of determination ranged from 0.48 to 0.78. After reviewing logarithmic model and power model that having high value of coefficient of determination, the logarithmic model which approached the last field measurement was adopted as the retroreflectivity decay model.



(a) Linear model



(b) Logarithmic model



(c) Power model (d) Exponential model

Figure 4. Regression Curve for White Durable Type on Concrete

Table 1 represents the lifetime prediction of each type. Lifetime means the elapsed time when the marking can maintain the minimum retroreflectivity values from the installation. For example, Since the minimum retroreflectivity value for the white marking is 150mcd/m^2/lux, Lifetime prediction (CVE) of the white conventional type on asphalt concrete is 304,950, that is Y=150 and X=304,950 in the retroreflectivity decay model. Consequently, on the area where traffic volume is 5,000, the elapsed time is estimated to be 61 days, that is, 304,950 divided by 5,000 is 61.

Table 1. Lifetime Prediction of Each Type

Material	Retroreflectivity Decay Model	Lifetime Prediction (CVE)
White conventional type on asphalt concrete pavement	$Y=1891.4X^{-0.2007}$	304,950
Yellow conventional type on asphalt concrete pavement	Y=-15.873ln(x)+334.26	1,367,362
White durable type on asphalt concrete pavement	Y=-37.507ln(x)+681.51	1,426,814

Table 2 represents the estimated durability of white conventional pavement marking on the asphalt concrete pavement. It was offered according the traffic volume using the linear model and the power model. As shown in Table 2 and Figure 5 the estimated durability varied definitely according to the traffic volume. On the site where ADT is about 5,000, the estimated durability of markings can be preserved during more than a year. However on the site where ADT is about 20,000, the estimated durability of markings drops to the minimum retroreflectivity value after only four months.

TABLE 2 Estimated Durability of White Conventional Marking on Asphalt

Traffic Volume (vehicles/lane)	Age (month)	CVE (10^5· vehicles· day)	Linear Model (mcd/m^2/lx)	Power Model (mcd/m^2/lx)	Average (mcd/m^2/lx)
5,000	0	0	251	278	265
	1	2	242	262	252
	2	3	233	247	240
	3	5	224	232	228
	9	14	170	162	166
	10	15	161	153	157
	11	17	152	144	148
	12	18	143	135	139
	13	20	133	127	130
	14	21	124	120	122

	15	23	115	113	114
10,000	0	0	251	278	265
	1	3	233	247	240
	2	6	215	219	217
	5	15	161	153	157
	6	18	142	135	130
	7	**21**	**124**	**120**	**122**
	8	24	103	106	106
15,000	0	0	251	278	265
	1	5	224	232	228
	2	9	197	194	195
	3	14	170	162	166
	4	19	142	135	139
	5	**23**	**115**	**113**	**114**
	6	27	99	94	91
20,000	0	0	251	278	265
	1	6	215	219	217
	2	12	179	172	176
	3	18	142	135	139
	4	**24**	**106**	**106**	**106**
	5	30	70	84	77

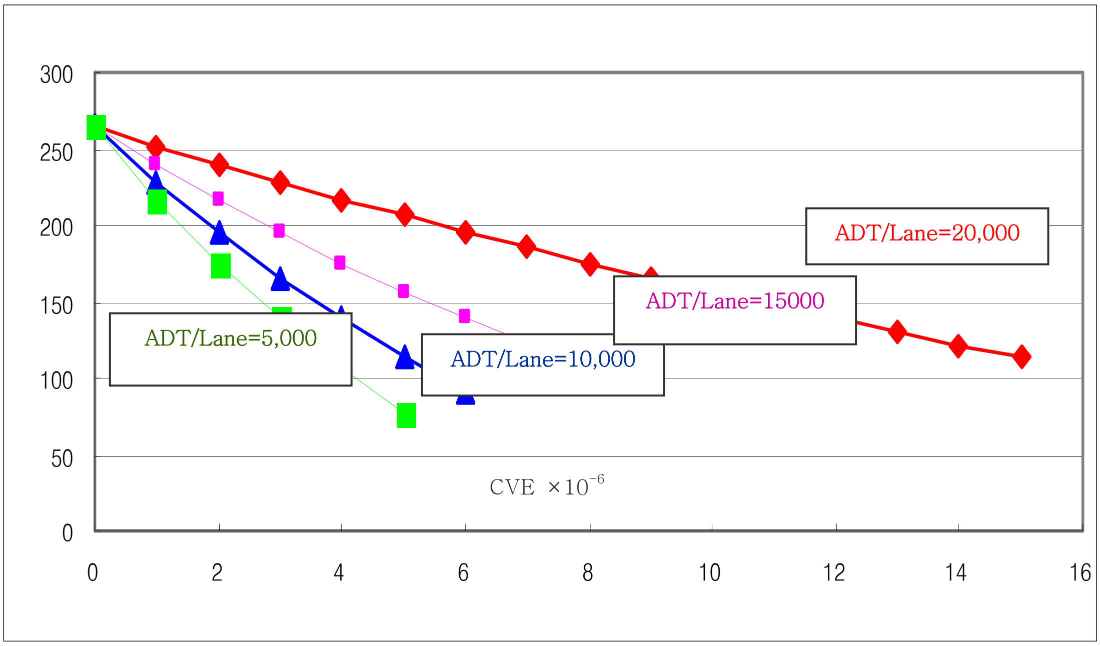


Figure 5. Estimated Durability According to Traffic Volumes

Table 3 represents the regression curve for markings on each site. Since field data was gathered total six times at the interval of three months for the period of two years, at each site the regression curve was obtained using six points. Applying this method, it was possible to develop the decay model for markings on the specific site and to reflect field features. Consequently, the decay model for each color, pavement, material and traffic volume was developed respectively and which may be used for the prediction of the residual performance of markings on each site.

Table 3. Regression Curve for Markings on Each Site

Classification			Retroreflectivity Decay Model	Coefficients of Determination (R^2)
Color	White		Y=-68.92ln(X)+153.51	0.9947
	Yellow		Y=-43.19ln(X)+113.82	0.9823
Pavement	White	Asphalt	Y=-62.88ln(X)+138.96	0.9966
		Concrete	Y=-73.58ln(X)+168.71	0.9910
		S M A	Y=-66.61ln(X)+153.92	0.9874
	Yellow	Asphalt	Y=-40.45ln(X)+106.13	0.9777
		Concrete	Y=-48.68ln(X)+112.18	0.9870
		S M A	Y=-39.71ln(X)+117.30	0.9857
Marking Material	White	Conventional	Y=-55.01ln(X)+127.45	0.9951
		Durable	Y=-71.83ln(X)+163.07	0.9874
		Water borne	Y=-87.17ln(X)+258.16	0.9849
		Modified acrylic	Y=-68.81ln(X)+153.42	0.9882
	Yellow	Conventional	Y=-46.31ln(X)+118.79	0.9928
		Durable	Y=-446.78ln(X)+111.41	0.9973
		Water borne	Y=-37.03ln(X)+104.42	0.9011
Traffic Volume (ADT)	White	5,000~10,000	Y=-59.41ln(X)+134.45	0.9967
		10,000~15,000	Y=-68.37ln(X)+159.32	0.9942
		15,000~20,000	Y=-77.95ln(X)+169.18	0.9839
		20,000~25,000	Y=-75.33ln(X)+153.35	0.9876
		More than 25,000	Y=-135.26ln(X)+246.49	0.9765

Figure 6 represents the comparison between prediction values and measurement values of retroreflectivities of the conventional type on asphalt concrete pavement. Prediction values were calculated using the performance decay model and measurement values were gathered on the field at the point of time to go on a year since the installation of markings. As shown in the figure, prediction values by the performance decay model were approached to measurement values.

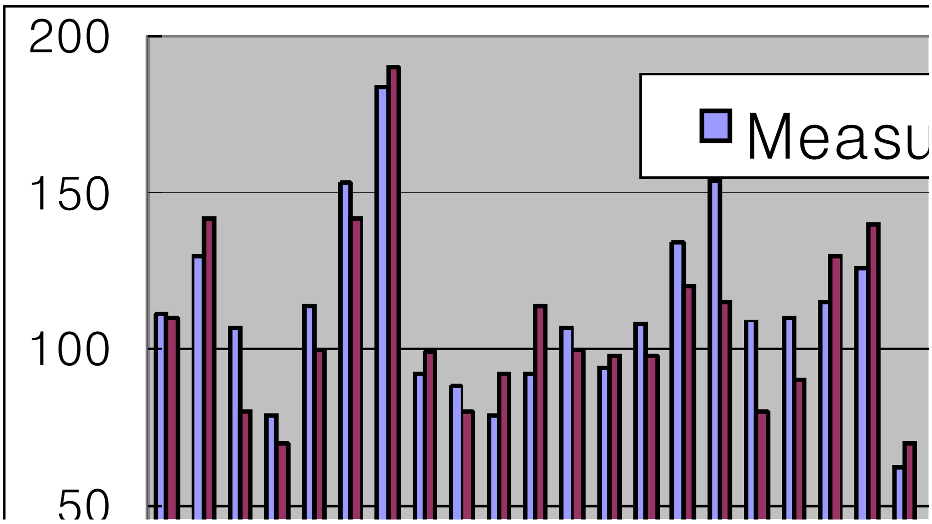


Figure 6. Comparisons between Prediction Values and Measurement Values

3. CONCLUSIONS

In this study, the performance decay model was developed and then the residual performance was predicted.

First, the regression curve was calculated by considering the factors affecting the performance of pavement markings respectively. As a result of the regression analysis, the logarithmic model was appropriate to field data and coefficients of determination ranged from approximately 0.90 ~ 0.99.

Secondly, the regression curve was calculated by considering traffic volume and age simultaneously. The performance decay model for each material on the specific site was developed. For accurate characterization of degradation curves, the markings were subdivided and separate models were developed. As a result of the regression analysis, the logarithmic model or power model was appropriate to field data and coefficients of determination ranged from approximately 0.72 ~ 0.78. The residual performance to maintain the minimum retroreflectivity was 1,429,989 vehicles for the white conventional type on asphalt concrete pavement, 4,820,535 vehicles for the yellow conventional type on asphalt concrete pavement and 4,145,037 for the white durable type on asphalt concrete pavement. Applying traffic volumes on the specific site, the residual time to maintain the minimum retroreflectivity can be calculated.

Maintenance activities such as snowplowing and remarking influenced retroreflectivity values significantly. They had to be considered for rational formulation of models. The findings of this study may prove especially useful to highway agencies that rarely implement snow plowing activities. It is recommended that aspects of pavement marking performance other than retroreflectivity such as wear and adhesion to the pavement surface must also be considered when determining if a making should be replaced.

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